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GOVERNMENT ROLE IN AN OIL SHALE DEMONSTRATION PROGRAM

by

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(1) Options III (in situ-mine) and IV (in situ nuclear) offer the possibility of greatest improvement in cost (See B), but by the same token costs are less certain for these.

(2) Nuclear in situ (IV) appears significantly cheaper than all other options. Its capital costs are much lower than all other options considered.

(3) Upgrading (i.e., reduction in nitrogen, sulfur and viscosity) in the field was estimated at $1.56 per barrel, a significant fraction of the oil cost. It may be possible to transport the crude to an oil refinery instead of requiring upgrading at the source. Diluents, pipeline heaters, etc. may be used, for example. Then upgrading (removal of sulfur and nitrogen) could be integrated into usual refinery operations, and considerable savings would occur. Alternatively the in situ process may not require upgrading or other treatment for transport by pipeline.

In such a case the nuclear option would show the greatest percentage savings in cost per barrel and capital investment, and its economic attractiveness would be still greater.

B. <u>Potential for Improvement in Technology and Economics</u>

(1) Surface retorting plus mining (either underground or pit) are the most developed options, and so have the greatest degree of certainty for success. At the same time surface retorting gives

oil yields approaching 100% and is less likely to show significant improvements in cost with time (learning effect).

(2) By the same token, in situ retorting processes (mined and nuclear) are assumed to have oil yields of 60%, with little past experimental development. Likely developments may well improve the yields significantly and lower the costs.

C. Resource Utilization

(1) The most developed option, I, surface retorting and underground mining, also recovers the least amount of resource, 5 to 10% of that available.

(2) Open pit mining in conjunction with surface retorting recovers the largest fraction of the resource, as much as 800 billion barrels of oil. However, this results in profound surface disturbance and a high price is required to obtain amounts approaching 800 billion barrels. It also appears to be the option that takes longest to begin to produce oil in significant quantities.

(3) In situ mining and retorting (Option III) has high resource utilization. As it develops, it may utilize even more of the resource as its yield improves and if the size of rubble chimneys can be increased, leaving the least amount of unretorted shale as partitions between adjacent chimneys.

(4) The degree of resource utilization of nuclear in situ, Option IV, is the most uncertain. The assumption has been made that approximately 50% of the oil shale is left unretorted between adjacent

chimneys and the oil yield is assumed to be 60%. Experience may show either improvement or degradation, i.e.:

(a) spacing between chimneys may have to be farther apart to prevent surface release of radioactivity through an adjacent chimney during a nuclear detonation.

(b) material between adjacent chimneys may be at least partially retorted during operation of the chimneys, adding significantly to the oil yield.

(c) yields may be increased beyond 60% (or they may not even reach 60%, a less likely situation) in further development studies.

D. Environmental Effects

(1) Open pit mining, II, disfigures the surface to the greatest extent, in removing both overburden and ore.

(2) The nuclear option, IV, disturbs the surface the least, requiring no removal of material from underground. However, it has the possibility of release of radioactivity to the surface during development of the technology. This may be kept to negligible levels or even eliminated totally after the first few field tests. It also will result in measurable radioactivity in the oil product. The level would be very low, apparently less than 0.1% of natural background and whether this is acceptable is a political and social decision. Finally, the spent shale, after retorting, is rendered radioactive and will remain so for

long periods. Some slight leaching of the radioactivity into ground water may occur. This is expected to be extremely slow and the effects will likely be undetectable other than underground and in the immediate vicinity of the nuclear chimneys. Nevertheless, without further research, one cannot give assurances that the groundwater activity will be undetectable.

(3) The mining in situ option (III) requires surface disposal of material much smaller in quantity than Options I and II. This is attractive, but it must be noted that the quantity to be disposed of is still not negligible (about 20-30% of Option I, i.e., that required by underground mining and surface retorting). As the process is further developed, it may be possible to reduce the amount of material removed to the surface (reduce the allowable void fraction in the rubble chimney) and so reduce the amount of surface disposal. However, this requires further development.

(4) Population influx into the Piceance Basin in Colorado is largest for the Options I and II. It may not be a fair comparison, however, since in our analysis Option II is using a leaner oil shale and uses much more of the resource.

Nuclear Option IV shows by far the smallest population influx, and Option III is intermediate.

E. Safety

(1) Option I, underground mining and surface retorting, has the highest estimated accident and fatality rate, other things

being equal. Underground mining is by far the most hazardous operation used. Options I and II are comparable in our present analysis largely because a much larger oil shale resource is used and the average oil shale quality is lower (20 gal/ton instead of 30 to 35 gal/ton). Thus much more material is handled and processed.

(2) Nuclear Option IV has by far the lowest accident and fatality rate.

(3) Option III, non-nuclear in situ, is safer than, but more comparable to I, underground mining, and II, open pit, in hazard. It may improve as the amount of material which must be removed to the surface is reduced with process improvement. However, underground retorting increases the hazard because of ventilation problems.

<u>Special Limitations</u>

(1) For Options I, II and III to be performed in the limited time assumed, government and the public in general must accept the notion of surface disposal of shale.

(2) Nuclear Option IV is yet undemonstrated in practice. As a result the risks to be faced are:

   (a) possible failure to obtain oil in the yield assumed (60%), and

   (b) possibility of radioactivity release during the first few nuclear detonations.

In addition, the government and the public must accept that very low level, but measurable, radioactivity will probably appear in

the oil product, and that ground shock will occur in the area during each detonation.

(3) Option III has its technical uncertainties. One must demonstrate that separating underground operations from retorting, which produces toxic and hazardous gases, is possible, and also that oil may be obtained in yields of 60% or more in large underground chimneys.

Timing to 100,000 bbl/day Operation

(1) Nuclear Option IV seems the one that will produce 100,000 bbl/day oil most rapidly, viz., beginning in three years. This assumes that formation of and oil retorting in the first few nuclear chimneys will be successful, and will be done within the first two years.

Time to expand to one million barrels per day is more difficult to assess.

(1) It appears that the in situ approaches lead to the most rapid development, viz., about 7 years. For the nuclear case, however, this presupposes the availability of approximately 300 drill rigs operating simultaneously, available manpower, and full production of nuclear explosives (100 to 130 per year). For the non-nuclear case a demonstration plant would have to be undertaken as soon as possible and priorities for labor and material would be required. Such an expansion is possible, given a crash program approach.

(2) It is estimated that Options I, and II could reach the production goal in 8-12 years. There is serious concern whether there would be sufficient numbers of underground miners and equipment to reach this goal in this time frame for Option I, underground mining and surface processing. Production of above-ground retorts must be fabricated in large quantities for Options I and II.

Table 6 summarizes the relative advantages and disadvantages of the various processes.

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GOVERNMENT ROLE IN AN OIL SHALE DEMONSTRATION PROGRAM

Summary

As an outgrowth of AEC Chairman Ray's energy report to the President on December 1, 1973, several energy demonstration projects that appear to have some potential for near term new energy production are being examined. This report considers the desirability of government participation in one or more commercial scale oil shale demonstration projects. The study approach was to estimate what the rate of oil shale development would be without additional Federal Government incentives or participation, identify the limiting factors to development, examine what government action could be taken to increase this rate of development and determine what a reasonably accelerated rate of development would be. Important consideration was given to the need to involve maximum industrial participation and funding and to carry out the projects in the most environmentally acceptable manner possible so that they could become standards for future energy development activities.

An attempt was made to apply the concept of utilizing present technology in demonstration projects that could lead to significant production of oil from oil shale within this decade. In examining the problems of developing such a large and potentially important resource as oil shale, it was found that the need to demonstrate a present technology on a commercial scale is but one of many factors holding back the rapid development of an oil shale industry. The charter for this study was therefore interpreted somewhat more broadly and in addition to identifying projects which can demonstrate

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present technology, other factors have been identified which must be overcome in order to move oil shale processing technology forward. In the case of in situ methods, not only has present technology been included, but technology that might be developed in a short time with a high probability of success has also been included. Successful demonstration of the in situ process could accelerate the rapid development of a large scale industry by reducing some of the limiting factors, such as the massive capital, equipment and personnel requirements and resulting time required with present surface technology. Additionally, the in situ technique may be more acceptable since it requires significantly less water than surface processing and has the potential of greatly reducing the environmental problems.

Although the present Department of the Interior oil shale leasing program constitutes a deliberate, orderly development of the resource, it is unlikely to result in the large production rates that "Project Independence" hopes to achieve by the end of this decade. This is due to limitations built into the prototype leasing program such as (1) the six lease tracts constitute a very small fraction of the government oil shale lands, (2) commercial development cannot begin for two years while baseline environmental data are being collected, and (3) there will be no expansion of leasing beyond the prototype program until it has been fully evaluated (this could be interpreted to mean until commercial scale plants have been in operation on the lease tracts for some period of time). Estimates of the amount of oil which will be produced from oil shale from the leased tracts plus private holdings range from a high of 300,000 barrels per day

by 1980 to a low of 100,000 to 250,000 barrels per day by 1985. The high estimate was included in the environmental impact statement for the oil shale leasing program, and the low estimate was made by the Coal and Oil Shale Technical Panel which was formed to provide input to Dr. Ray's December 1 Federal Energy R&D report to the President. For comparison it is estimated here that an early successful demonstration of a commercial scale oil shale processing plant, along with other identified government actions, could result in production of one million barrels per day of oil from oil shale by about 1983 and possibly two years sooner if in situ processing is successful.

The government role in the oil shale demonstration program will consist of coordination and planning, providing selected financial incentives and minimizing administrative and legal delays. Two types of demonstration projects are recommended to offer the highest probability of success. The first one is to demonstrate the in situ process on a scale of 30,000 to 50,000 barrels per day. This will require significant government involvement due to the technical risk inherent in a larger than normal scale up. Such a plant would cost approximately $150 to 200 million, including product upgrading facilities to produce a high grade syncrude, and could be completed by mid-1977. Government financial support would be offered via a guaranteed loan or direct government loan for a portion of the capital costs. A guaranteed product price should also be considered. Selection of the industrial partner(s) would be by competitive bid. An accelerated in situ R&D program would be conducted in conjunction with the demonstration plant. A second alternative which deserves further study because of the

less advanced state of the in situ technology is joint government/industry funding and management with terms to be negotiated. This approach would result in a greater assurance that the plant would be undertaken on the desired schedule but would have the disadvantage of less industry involvement.

The second recommended project is to demonstrate at least one surface processing plant at 50,000 barrels per day. This would require less government involvement due to the more advanced state of the technology and subsequent lower level technical risks. Such a plant would cost approximately $300 million and could also be completed by mid-1977. Selection of the industrial partner(s) would be by competitive bid. A decision on whether to participate in more than one surface processing demonstration plant could be based on the bid proposals received. An alternate to this project is to build one or more commercial scale surface retorts, about 8,000 barrels per day each, in conjunction with the in situ plant.

Government participation in a surface demonstration plant would offer a high degree of assurance that such technology would be available and that related economic, institutional and environmental questions would be answered at the earliest date possible. However, it should be noted that a commercial scale plant undertaken entirely by industry on either private or leased land would provide answers to most of the same questions. It is possible that if the government would establish a policy which encourages early oil shale development, such as making additional high grade government land available, and would undertake the other actions outlined in

this report in support of the demonstration program, initial commercial scale surface type plants might be built on nearly the same schedule and without direct government participation or financial incentives. However, since there is no assurance that private industry will undertake construction of these plants independently, and in view of the critical energy situation, limited government participation in surface type oil shale demonstration plants is justified. It seems clear that industry will not undertake construction of an in situ demonstration plant in the near future without government participation and risk sharing.

For the demonstration plants to progress at the desired rate, several additional government actions would be required. A major purpose of the demonstration plants, other than demonstrating the technology, is to show whether they can be designed, constructed, and operated in an environmentally acceptable way, and to illuminate and seek solutions to the institutional problems which may be roadblocks to development of an oil shale industry. Appropriations legislation would be required, and possibly authorizing legislation if the desired actions cannot be taken under existing legislation such as the Defense Production Act of 1950, or the Atomic Energy Act of 1954.

Other important government actions required in support of this program are: (1) the establishment of a policy which encourages the growth of an oil shale industry, such as a stated national objective of rapid oil shale development and a long range leasing policy; (2) a decision to allow demonstration plants to be built on leased or other government land (there is presently a clearly stated policy that construction cannot begin on the prototype lease tracts for two years to allow the collection of environmental baseline data and that there will be no expansion of leasing beyond

the prototype program until it has been fully evaluated); (3) priority allocation of labor and materials to support accelerated development; (4) establishment of a procedure for rapid processing of permits and licenses (may require legislative action); and (5) accelerated preparation and processing of environmental statements.

After demonstration plants are completed, additional government actions to assure the development of a viable industry include: (1) a legislative revision to allow a company to lease more land than 5,120 acres; (2) joint Federal, state and local planning for the supporting communities and services which will be required as well as Federal Government cost sharing for these activities; (2) possible financial incentives in the form of more advantageous tax laws; (4) joint Federal, state and local planning for regional resource development (e.g., oil shale, natural gas, coal); (5) coordinating effort by the Federal Government to assist state and local governments in a standardization of Federal, state and local regulation of the industry; and (6) a continuation of supporting R&D, particularly concerning area hydrology, environmental effects, mining technology capable of recovering the thicker deeper deposits, and nuclear explosion technology development to provide one more option which could be developed quite rapidly if proven and accepted.

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GOVERNMENT ROLE IN AN OIL SHALE DEMONSTRATION PROGRAM

I. Introduction

In the transmittal letter of her report to the President on Federal Energy R&D of December 1, 1973, Chairman Ray stated, "Considerations for using today's technology to meet and overcome the present energy crisis, and to be responsive to 'Project Independence,' are being submitted separately." The necessity for meeting immediate and projected large energy demands; a rapidly decreasing ability to meet these demands from conventional domestic energy supplies; and recent increases in the price of foreign oil, all focus attention on the urgent need for developing supplemental domestic energy sources as rapidly as possible. Oil shale constitutes an enormous potential source of fossil fuel energy and should receive major attention by both government and industry. This study examines the desirability from a policy view of government participation in one or more oil shale demonstration projects and investigates the potential for demonstration of the various processes on a commercial scale with minimum effect on the environment using near term technology. The potential for long range commercial development is also examined. Two large scale demonstration projects are recommended and a number of alternatives are identified.

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An attempt was made to apply the concept of utilizing present technology in demonstration projects that could lead to significant production of oil from oil shale within this decade. However, in the case of in situ methods (processing the shale in place underground) not only was present technology included but technology that might be developed in a short time with a high probability of success was also included. In situ processing could accelerate the rapid development of a large scale industry by reducing some of the limiting factors such as the massive capital equipment and personnel requirements and resulting time as compared to the surface processing approach. The in situ technique could also result in a lower product cost, greatly reduced environmental problems and a significantly reduced water requirement.

In examining the problems of developing such a large and potentially important resource as oil shale it was found that the need to demonstrate the technology on a commercial scale is but one of many factors holding back the rapid development of an oil shale industry. Therefore, in addition to identifying demonstration projects other factors have been identified which must be overcome concurrently in order to move the technology forward as rapidly as possible.

Large areas of the United States are known to contain oil shale deposits, but those areas in Colorado, Utah, and Wyoming

that contain the organic-rich sedimentary rocks of the Green River Formation have the greatest potential for shale oil production. These oil shale deposits occur beneath 25,000 square miles of land, of which about 17,000 square miles are believed to contain oil shale of possible value for commercial development (Figure 1). The thickest and richest deposits, however, occur in the north central part of the Piceance Creek Basin. For example, 720 billion barrels of oil are contained in an area of about 600 square miles, averaging greater than 400 feet in thickness and containing more than 20 gallons per ton. An estimate of the potential oil contained in these deposits depends on the cut-off values used for thickness and grade. Estimates of the amount of oil in place as a function of thickness and grade are summarized in Table I.

The amount of recoverable resource also depends on the process used to recover it as will be pointed out later.

Two general approaches, with two major variations each, have been considered for the recovery of shale oil. One of these involves mining the shale, crushing it to a size suitable for the particular retorting process to be used, retorting it at 800° - 900°F to decompose the solid organic matter in it to oil, recovering the oil thus formed, and disposing of the residual spent shale. The second approach involves the use of naturally occurring or artificially created permeability underground followed by in situ

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OIL SHALE AREAS COLORADO, UTAH, AND WYOMING

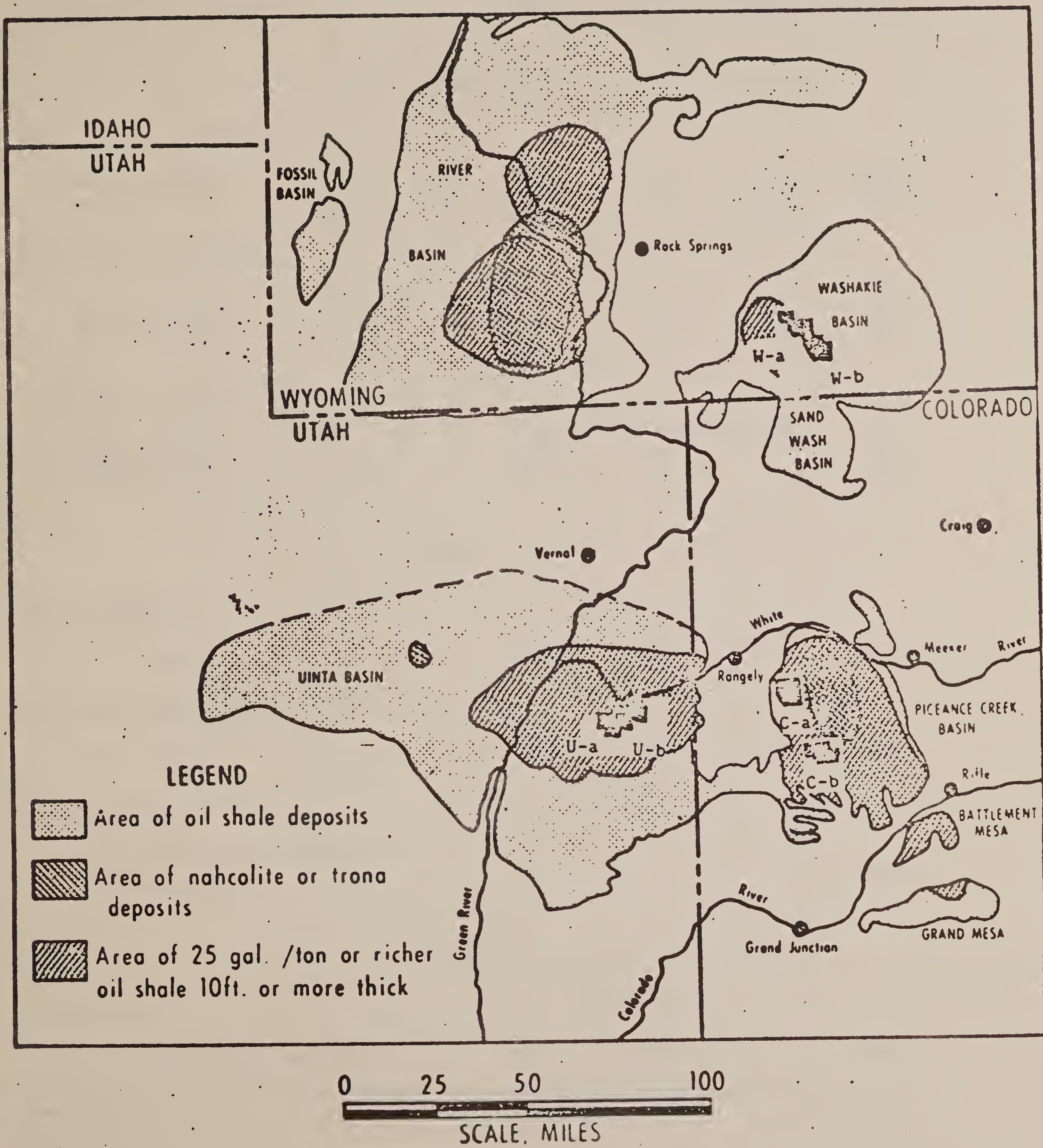

FIGURE 1[b]

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[b] References 1 or I-2

TABLE 1. - Estimates of Oil in Oil Shale of Green River Formation

Oil Grade and Thickness	Oil in place--billion barrels Colo.	Utah	Wyoming	Total
LLL[a]				
More than 15 gal/s.t.				
400 ft thick	790	70	0	860
800 ft thick	700	0	0	700
More than 20 gal/s.t.				
400 ft thick	720	0	0	720
800 ft thick	640	0	0	640
More than 25 gal/s.t.				
100 ft thick	490	(not estimated)		490
500 ft thick	350	0	0	350
1000 ft thick	270	0	0	270
USBM[b]				
10-25 gal/s.t.				
10 ft thick	800	230	400	1430
More than 25 gal/s.t.				
10 ft thick	480	90	30	600
30-35 gal/s.t.				
25 ft thick and 1000 ft below surface				160
NPC[c]				
30 gal/s.t.				
30 ft thick and "mineable"	82.6	11.5		94.1

[a]Reference 2
[b]Reference 3
[c]Reference 4

processing in which the oil shale is heated in the ground to retorting temperatures and the liberated oil is brought to the surface. A column of oil shale rubble may be prepared for in situ processing by mining and the use of conventional explosives or by a nuclear explosion with no mining required.

In the first approach either surface or underground mining may be used, but so far nearly all of the effort in developing mining techniques for oil shale has been devoted to the underground room-and-pillar method. Several above-ground retorting systems have been tested on a pilot scale but none has been demonstrated on a commercial scale. Disposal of spent shale in an environmentally acceptable manner presents problems which will require further investigation.

Only recently has an appreciable effort been devoted to the in situ approach. There are a number of ways in which access to the shale can be achieved, heat supplied for retorting the shale, and the products recovered. However, so far only one--a combined mining and collapse technique to prepare the shale for retorting followed by combustion with air to supply the required heat--has been successfully demonstrated in an operation of sufficient size to indicate the possibility of near term commercial application. A more complete description of the various mining and retorting processes is provided in Appendix A.

Each of the four basic approaches for processing oil shale (surface mining and surface processing, underground mining and surface processing, in situ processing with some underground mining, and in situ processing with the use of a nuclear explosion) has inherent advantages and disadvantages. Surface processing of shale obtained by either underground or surface mining, although the furthest along in development at this time, requires relatively large amounts of water, primarily for spent shale disposal, and will require a significantly larger influx of people into a presently sparsely populated area. Underground mining would recover the least amount of the existing resource, approximately 54 billion barrels[d] assuming 30 gallon per ton and higher shale is mined. Surface mining utilizes the maximum amount of resource, over 700 billion barrels, assuming shale of 20 gallon per ton and higher would be recovered by that method.

Each of the surface processing approaches presents a serious spent shale disposal problem. Surface mining causes the largest disturbance to the ground surface. The underground mining and in situ processing approach, although at an earlier stage of development, offers the advantages of lower capital costs; lower water requirements; the influx of fewer people; very low level land surface disturbance and a substantially reduced disposal problem. In situ processing in conjunction with the use of nuclear explosives

[d] Reference 4, pg. 10

has not been tested on even a pilot scale although available information indicates that if successful such an approach would require the least amount of capital, and result in the smallest amount of population influx. Water requirements would be relatively small and there would be no spent shale disposal problem. This technique will require testing to assure that radioactive leakage will not occur. Public acceptance would have to be obtained. One disadvantage of the in situ process is that it would make more difficult, if not eliminate, the possibility of recovering associated minerals. A detailed discussion of the advantages and disadvantages of each process is presented in Appendix B.

In addition to the mining and retorting operations it may be necessary to upgrade the produced shale oil to reduce its viscosity, so that it can be piped, and to remove nitrogen and sulfur so that it can be used as a normal refinery feedstock.

In summary, several processes for both above ground and in situ retorting have been tested on a small scale. Several of these could be scaled up to demonstrate commercial feasibility almost immediately. In most cases, particularly for in situ operations this would involve more than normal amounts of risk. Two companies have, however, announced plans to build commercial scale plants, using surface processing, within the next six years.

As can be seen from Figure 1, there are large areas of nacolite deposits which are found with the oil shale. Also, dawsonite, a potential source of aluminum, is found with the shale in certain areas. Several thousand feet below the oil shale there are low permeability gas-bearing formations. The purpose here is not to suggest a particular method for developing these resources, but to point out that a coordinated multiresource development plan is needed so that in the process of removing one resource we do not unconsciously prevent the future retrieval of another important resource.

II. Potential and Time Frame for Development of an Oil Shale Industry

The present Department of Interior prototype oil shale leasing program calls for the leasing of six 5,120 acre tracts, two each in Colorado, Utah and Wyoming (Figure 2). The objectives of the program are to stimulate development of commercial oil shale technology in a manner that will have minimum environmental impact and provide for rehabilitation of the immediate and surrounding affected areas. The program involves competitive lease offerings for cash bonuses with minimum royalty payments beginning in the sixth year and accelerating thereafter to encourage development and actual production. One-fifth of the bonus will be paid at the time of bidding and one-fifth at one-year intervals. An arrangement whereby development costs can be credited against the last two bonus payments is included to encourage the start of development in the third year of the lease.

The first lease sale, which was for the Colorado -a tract, was held on January 8, 1974. The remaining five lease sales will be held at monthly intervals in the following order; Colorado -b, Utah -a, Utah -b, Wyoming -a and Wyoming -b. Colorado -a contains the largest estimated recoverable reserve and also has the potential for both underground and surface mining. Table 2 shows the total recoverable oil shale resources for each tract and the expected extraction method.

GENERAL GEOGRAPHIC LOCATION OF THE SIX OIL SHALE TRACTS IN COLORADO, UTAH, AND WYOMING[c]

[c] Reference 5

FIGURE 2

TABLE 2.[d] ESTIMATED RECOVERABLE OIL SHALE RESERVES

(developed by DOI for use in determining minimum royalty calculations)

Tract	Extraction Method	Estimated Recoverable Oil Shale Reserves
Colorado C-a	Underground - Note: If Surface Mining is used, the same values would be applicable.	1,857,000,000 tons in mineable beds containing 30 or more gallons per ton.
Colorado C-b	Underground	1,012,000,000 tons in mineable beds containing 30 or more gallons per ton.
Utah U-a	Underground	342,000,000 tons in mineable beds containing 30 or more gallons per ton.
Utah U-b	Underground	372,000,000 tons in mineable beds containing 30 more gallons per ton.
Wyoming W-a	In Situ	354,000,000 tons in mineable beds containing 20 or more gallons per ton.
Wyoming W-b	In Situ	352,000,000 tons in mineable beds containing 20 or more gallons per ton.

[d] Reference 5

The highest lease bid for Colorado -a was $210 million by Standard of Indiana and Gulf Oil Corporation. Table 3 is a tabulation of the bonus bids for the Colorado C-a lease tract. These bids indicate a high degree of interest on the part of industry.

TABLE 3 - Oil Shale Bonus Lease Bids

Company	Bonus Bid	Per Acre Price
Standard Oil of Indiana and Gulf	$210,305,600	$41,319.84
Sun Oil of Delaware	175,001,190.98	34,383.40
Marathon, American Petrofina, Phelps-Dodge	80,000,000	15,718.02
ARCO, Ashland and TOSCO	63,333,333.36	12,443.44
Shell Oil	63,000,000	12,377.94
Carter Oil	33,125,294.51	6,508.30
Occidental Petroleum	16,361,044.24	3,214.54
Norm S. Shaw, San Diego	49% of net profits $1.00 token bid	

According to the lease arrangements, however, substantial development cannot begin before the end of the second year since baseline environmental data must be collected for two years before commercial operations. In Secretary Morton's Decision Statement of November 28, 1973, regarding the leasing program he stated, "It will be several years before we determine whether oil shale will help solve our problems."

The "Final Environmental Statement for the Prototype Oil Shale Leasing Program" contains an estimated development schedule. It indicates that by 1980 there may be 3 plants on the leased lands, 2 in Colorado and 1 in Utah, producing a total of 200,000 barrels of oil per day. Two additional plants on private lands are assumed to be producing another 100,000 barrels per day for a total oil production from oil shale of 300,000 barrels per day by 1980. Others have estimated that under a normal evolutionary process, shale oil production may be limited to 100,000 to 250,000 barrels per day by 1985. It would seem that to achieve a significantly higher rate of production by the early 1980s would require substantial modification if not a complete change in the present oil shale leasing program.

An alternative to the normal evolutionary process and the present leasing program is to adopt emergency measures to reduce anticipated oil shortages in the least possible time consistent with environmental constraints. This would involve major Government action possibly including special legislation to authorize the immediate design and construction of commercial scale demonstration plants. Such demonstration projects would involve maximum industrial participation and funding. They would be carried out in the most environmentally acceptable manner possible so that they could become standards for future energy development activities.

Assuming that such demonstration plants could begin in mid-1975, sufficient knowledge and know how should be available by late 1977 to begin detailed engineering design of several 100,000 barrel per day oil shale plants and to allow construction of these plants to begin by mid-1978. With proper planning and management such an effort could result in production of 1 million barrels of oil per day from oil shale by about 1983 and possibly sooner if in situ processing is successfully demonstrated. (See detailed discussion and Table 4 in Section III). In an addendum to Chapter I of the report "Overview of an Integrated National Energy Research and Development Program" prepared as input to Chairman Ray's Energy R&D Report, it is stated that it would be possible to build 10 to 18 oil shale extraction plants each with 100,000 barrels of oil per day capacity by 1985. This amounts to 1 to 1.8 million barrels per day total capacity by 1985. A subgroup of the Coal and Oil Shale Technical Panel formed to provide input to the December 1, R&D Report stated, "Under emergency conditions, the maximum program, production by 1985 could reach 1.3 to 1.5 million barrels per day."

The ultimate rate of production of an oil shale industry may be limited by the amount of water available, although the competition for water should not be severe for the development and operation of a 1 million barrel per day industry. Adequate amounts of surface water are potentially available (341,000 acre-feet per year) to support a 1 million barrel per day industry which is expected to require from 121,000 to 189,000 acre feet of water per year.[e] This

[e] Reference 1, pg II-29 and III-34

includes the amounts which will be required by the supporting communities and population. A 3 to 5 million barrel per day industry could possibly be established, if all the water in the oil shale regions of Colorado, Utah and Wyoming were made available for oil shale development. This production rate might be greater if other potential sources of water, such as from underground, are developed and if in situ development were used. However, there will be competition for water in these regions by a minerals industry, for agriculture and possibly for coal gasification.

In addition to creating a demand for water, the creation of a significant oil shale industry will impact the region in other ways. The disposal of spent shale and other solid waste materials presents a serious environmental challenge. Assuming that all retorting facilities were of the surface variety, a one million barrel per day industry would require processing 570 million tons of shale annually (30 gal/ton). This tonnage approximates the current annual level of US coal production. It may be possible to return some of the spent shale to the mine, but at increased cost. Also, mine safety problems are associated with such an action and reburial would represent only a partial solution because of the increased volume created by bulking when the shale is mined. If production were obtained by non-nuclear in situ plants, perhaps as much as 25% of this volume, or 140 million tons, would have to be mined. The mined shale would probably then be processed in

surface plants to optimize overall economics. If a nuclear explosion were used to break the shale, no mining and therefore no disposal, would be required. However, this alternative has other inherent disadvantages which are discussed below.

The population of the region would also be affected by a large oil shale industry. The development of surface processing operations capable of producing one million barrels of oil per day would increase the population of the region by approximately 115,000 people. With an in situ process, the number of incoming people would be smaller but nevertheless considerable in relation to the current population. The influx of a large number of people into an extremely sparcely populated area will require careful planning to avoid undesirable social and environmental impacts.

The economic stability of the region would also be affected. We have estimated that a surface plant with a 100,000 barrel per day capacity and sufficient mining capability would require a capital investment of $600 million. A million barrel per day industry would thus require capital facilities of $6 billion. In situ plants would cost less, about $340 million each, but would still require a significant investment - $3.5 billion for one million barrels per day.

The remainder of this report will describe a demonstration program involving both in situ and surface processing (Section III);

define the government's role in such a program (Section IV); and outline the immediate actions required to implement such a program (Section V).

III. Project Alternatives

There are several criteria for selection of an optimum oil shale demonstration program. The most important, however, is the potential effectiveness in stimulating industry development which will result in significant oil production in the early 1980s in an environmentally acceptable way with high potential for large scale longer range production. Other criteria are; legal and administrative feasibility, political acceptability and cost to the government. The role of the government in the demonstration projects is discussed in Section IV.

In order to have the highest degree of confidence that nationally significant amounts of oil will be produced from oil shale in the early 1980s, it will be necessary to attempt to develop and demonstrate more than one method for processing the shale to obtain oil. It will also be necessary to demonstrate the complete operation from mining through retorting, upgrading of the product and in the case of surface processes, disposal of the spent shale. For the maximum rate of development, demonstration plant(s) should be on a commercial scale, a minimum of 30,000 to 50,000 barrels per day per plant, and should be operated with minimum environmental effects.

It was concluded that the in situ process should receive priority attention for several reasons. Its stage of development is less advanced than the surface processes and therefore scaling up to a commercial size would involve larger technical risks. In

situ processing has been demonstrated at a scale of 30 to 35 barrels per day versus almost 1,000 barrels per day for some surface processes. Because of the potentially large environmental advantages of the in situ process it is in the national interest to take these risks. The in situ process requires mining less than 25% of the amount required to obtain a comparable amount of oil from surface processing. The resulting lower capital costs would allow more rapid development and the potential of cost reduction through process improvement is large. The in situ process would also require significantly less water and fewer people would be involved. For these reasons government participation in an in situ demonstration plant is considered desirable and important.

Recommended Demonstration Plants

An in situ plant of 30,000 to 50,000 barrels per day capacity would be sufficient to demonstrate the technology on a commercial scale. It would be undertaken in such a way as to allow expansion to a capacity of about 100,000 barrels per day which is considered to be about optimum for a commercial operation. The cost of such a plant is estimated to be $150 million to $200 million including supporting product upgrading facilities. If construction began in mid-1975 such a plant could be in operation by mid-1977 and if successful, could lead to an industry production capability of about 1.8 million barrels per day by 1985.

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A surface plant of about 50,000 barrels per day capacity would be required to demonstrate that process on a commercial scale. For maximum acceleration of an oil shale industry as many as three of these plants could be built initially each using a different retorting process. Such plants would be expected to cost approximately $300 million each and could be constructed on about the same schedule as for an in situ plant.

Based on industry response to a government invitation for industry proposals, described in Section IV, a decision would be made as to whether participation in more than one surface processing demonstration plant should be undertaken. Estimated development schedules and production rates are included in Table 4 for both surface and in situ processing. For comparison estimated production rates without additional government action are also shown. It must be stressed here that government actions described in Section IV over and above participation in demonstration plants would be required to result in the estimated production rates and, further, that if these actions were taken industry might undertake first commercial scale surface processing plants on their own nearly as rapidly as with direct government participation.

To arrive at the estimates in Table 4 it was assumed that the availability of materials (e.g., heavy mining equipment), labor (particularly miners) and supporting facilities (towns, utilities, etc.) would limit the rate of construction of surface plants to about four

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Table 4. Estimated Development Schedules

(Nos. in parantheses indicate estimated production in 1,000 of barrels per day)

	74	75	76	77	78	79	80	81	82	83	84
Surface Processing (Accelerated)	Δ	o Begin const. of Demo. plants		o Complete const. & begin operation (100)*	o Begin const. of multiple comcl. plants		o 4 comcl. plants completed (400)**		o 8 comcl. plants completed (800)		o 12 comcl. plants completed (1200)
In Situ Processing (Accelerated)	Δ	o Begin const. of Demo. plant		o Complete const. & begin Operation (30-50)	o Begin const. of multiple comcl. plants		o 6 comcl. plants completed (600)***		o 12 comcl. plants completed (1200)		o 18 comcl. plants completed (1800)
Estimated Production Rates without additional Government Action							(0-200)		(100-300)		

Δ Decision to go forward with Demo plants and issuance of RFP to industry

* Two 50,000 bbl/d demo plants

** Completion of four 100,000 barrel per day commercial plants including scale up of two 50,000 barrel per day demo plants

*** Completion of six 100,000 barrel per day commercial plants including scale up of initial demonstration plant

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under construction at one time, that construction of these plants could begin after about 1 year of demonstration plant operation, and that they would require about two years to complete. This accelerated schedule would require priority allocations of men and materials. It was further assumed that after demonstration in situ plants could be built 50% more rapidly than the surface type, (6 plants under construction simultaneously and two years to complete) due to the reduced amount of mining and manpower required for comparable production. To simplify making the estimates it was assumed in each case that it was the only process being commercialized. More likely production would be from a combination of in situ and surface processes. It is expected for example, that the shale which must be mined for an in situ operation would be processed in a surface type plant for the best overall economics.

Even though there are indications that industry will develop surface processing independently, there are no assurances that significant production by 1980 will result without a major role being taken by the Government. Government funding should be less for surface plants than for the in situ plant because of the smaller technical risk, due to the relatively advanced stage of development. For example, the TOSCO II and Union processes have operated at a scale of 1,000 tons per day and the Petrosix process has been demonstrated at 2,500 tons per day in Brazil. A commercial plant would consist of a series of retorts each operating at about 10,000 tons per day.

Alternate Demonstration Projects

A lower cost alternate to the 50,000 barrels per day surface plant is the construction of one or more surface retorts, to demonstrate the maximum number of surface processes, in combination with and in close proximity to the 30,000 to 50,000 barrel per day in situ plant. Each retort would be of commercial size, 10,000 tons or about 8,000 barrels per day. They could utilize the shale mined for the in situ operation and could also use a common upgrading plant. The incremental costs would be a few million dollars per retort and they could probably be put in operation in early 1977. The time limitation would be the development of the mine. This is a more desirable alternative to the recommended program in certain respects, including lower cost, but would not be fully responsive to the objective of maximum production by the early 1980s.

There are several other alternatives which could be considered to either minimize costs, such as construction of a single commercial size retort (10,000 tons per day), or further accelerate production, such as building larger demonstration plants. A single 100,000 barrel per day plant consisting of two 50,000 barrel per day surface processing units utilizing different processes but supported by common mining and upgrading facilities would be a modification to the 50,000 barrel per day surface processing plant and might deserve further study. The smaller scale projects offer alternatives for demonstrating a commercial scale retort for both surface and in situ processing but

would not allow full scale commercial demonstration. They would probably require a large proportion of government funding since they would not be commercial operations. It is not clear whether they would speed up or hinder the overall rate of development. It is possible that industry would delay investing in first commercial scale plants until the results of these projects were known.

The development and demonstration of nuclear technology offers potential economic advantages but would require accepting the risk of some leakage of radioactivity during the first few detonations. This possibility exists because of the gas evolving properties of oil shale resulting from the temperature increase. This eventually could be safely handled with isolation or local evacuation of some of the oil shale lands. This may be politically unacceptable. The problem of possible leakage, however, could probably be answered by a series of more conservative tests, requiring a year or two and is the recommended approach. Development of oil shale by the use of nuclear explosives could then proceed rapidly, especially if the in situ retorting project has advanced the technology of this type of processing in the interim.

IV. Government Role

The government role in an oil shale demonstration program would be one of overall coordination and planning along with financial incentives and minimization of administrative and legal delays. One of the first things which will be required is a policy decision and announcement to allow demonstration plants to be constructed on presently leased tracts or on other government land. This would tend to contradict statements made in the Environmental Impact Statement prepared for the prototype leasing program to the effect that commercial activity could not begin for two years on the lease tracts and that there would be no additional leasing of government land until the prototype program is fully evaluated. A new environmental impact statement would therefore be required. In addition to the necessary legislation authorizing the appropriation of funds for the desired actions, basic authorizing legislation may be required if present authority under such laws as the Atomic Energy Act, the Clean Air Act or the Defense Production Act is insufficient to permit conduct of those actions.

It is proposed that if the demonstration concept is adopted an Office of Synthetic Fuels (OSF) be established to administer all commercial scale demonstration projects, including any for coal gasification and liquefaction and methanol production, as well as for the production of oil from oil shale. This office could be within

the Federal Energy Office, ERDA, if it is formed, or in the Department of Interior. OSF would be given authority to negotiate directly with industry to arrive at arrangements for joint government/industry participation. The objective would be to obtain maximum industry participation and funding. OSF would be given authority to provide a guaranteed product price, to guarantee non-resource loans to industry and to make direct loans to industry. However, the government should avoid assuming all of the financial risk. The OSF would prepare a request for proposals in which the desired demonstration projects would be described and the guidelines for selection of industry proposals would be specified. These guidelines would include the qualifications of the proponent, the technical, economic and environmental merits of the proposal, and the magnitude of the share of the total cost of the project which the proponent is willing to assume. Government willingness to entertain proposals for the construction of plants to produce oil from oil shale; to make long-term negotiated contracts guaranteeing to buy the output of the plants, if such output could not be otherwise sold at the support price; to guarantee or make direct loans covering a portion of the costs of such plants; and to make additional government land available, if necessary, would be indicated.

Some arrangements to provide equitable protection to the participants' rights to background patents, trade secrets, or proprietary information would be required. It might be agreed that such information would be made available to any qualified applicant on reasonable

license terms including suitable confidentiality agreements, reasonable royalties and other conditions, taking into account that commercial viability was achieved with the assistance of public funds. It may also be necessary in some cases to provide relief from anti-trust provisions which tend to restrict combinations of companies.

Recommended Government Role

For the in situ demonstration project, the government should expect to make a sizeable financial contribution, probably in the form of a direct government loan or a guaranteed non-resource loan, due to the larger risk involved. If the plant is successful, there would be no cost to the government since the loan would be repaid from profits. A second alternative due to the R&D nature of the in situ plant which needs further study is joint government/industry funding and management with terms to be negotiated. Government funding could amount to 50 to 75% of the costs of the plant. In the case of the direct or guaranteed loan, provisions would be made to require a minimum rate of development by the industrial sponsor. The government would have the option of completing construction or taking over the operation of the plant in the event the industrial sponsor failed to proceed at the agreed rate or chose to discontinue his participation. In the case of joint funding and management, provision would be made for the industrial sponsor to take over the plant and expand it to the most economical size, probably about 100,000

barrels per day upon completion of the demonstration phase. In any case there should be provision for the government to carry on an R&D program as a part of the project to obtain information which will be required to extend the applicability of the in situ approach to other parts of the basin.

For the one or more 50,000 barrel per day surface plants either minimal or no financial assistance should be required. Selection of the industrial participant and possible financial assistance, in the form of guaranteed or direct loans, could again be based on proposals from industry. The other approach for surface processing is to take those actions necessary to clear the way for rapid development by industry, described in succeeding paragraphs, but not offer direct government participation or financial incentives. The arguments for this approach are that the technology is at hand and industry has demonstrated willingness to spend significant amounts by the Colorado -a tract bidding.

Table 5 provides a summary of the costs of the two types of demonstration plants and an estimate of the amount of the financial risk which the government might have to take, probably in the form of a guaranteed or direct loan, in order to result in timely initiation of the plants.

TABLE 5 - Demonstration Plant Cost Estimates
($ millions)

	Total	Estimated Government Share of Risk
50,000 bbl/d surface plant	300	0 - 100
30,000 to 50,000 bbl/d in situ plant	150 - 200	75 - 150

The recommended government role of providing direct or guaranteed loans and possibly a guaranteed product price was selected to initiate prompt action on the demonstration plants and at the same time keep industry in its traditional role as owner and operator of fuel production facilities, with each company competing for a place in the market. It would also allow the Federal Government to share the initial risks of oil shale development with industry without becoming involved in ownership and operation.

A similar plan which could be incorporated in the same general framework would involve providing a 10-year contract to purchase through closed competitive bids a certain amount of synthetic crude oil derived from oil shale at a fixed target price per barrel. The government could then offer for sale annually to the highest bidders the shale oil it contracted to produce. If the highest bids were less than the contract purchase prices the government would incur a loss. It has been suggested that funds for underwriting the difference between purchase price and sales price could be derived from a levy on oil imports.

Tax incentives were thought to have more application to large scale development of a commercial industry after demonstration plants

have been built and operated. They would not allow any direct government control to assure that the desired actions were taken by industry.

It was also concluded that joint government-industry corporations or development by a government agency should only be considered in the event industry fails to respond to the recommended program.

Additional Government Actions Required

One of the most important government actions required to meet the estimated production rates in Table 4 of Section III is a stated national policy to develop a U.S. oil shale industry as rapidly as reasonably possible. Such a policy should allow initial demonstration plants to be built on presently leased tracts and possibly also make additional government land available for that purpose. A special office should be established and given the authority to provide a guaranteed product price and direct and guaranteed loans. Important actions which the government should take in support of accelerated oil shale development are: (1) the establishment of a policy which encourages the growth of an oil shale industry, such as a stated national objective of rapid oil shale development and a long range leasing policy; (2) a decision to allow demonstration plants to be built on leased or other government land (there is presently a clearly stated policy that construction cannot begin on the prototype lease tracts for two years to allow the collection of environmental baseline data and that there will be no expansion of leasing beyond the

prototype program until it has been fully evaluated); (3) priority allocation of labor and materials to support accelerated development; (4) establishment of a procedure for rapid processing of permits and licenses (may require legislative action); and (5) accelerated preparation and processing of environmental statements.

After demonstration plants are completed, additional government actions to assure the development of a viable industry include: (1) a legislative revision to allow a company to lease more land than 5,120 acres; (2) joint Federal, state and local planning for the supporting communities and services which will be required as well as Federal Government cost sharing for these activities; (3) possible financial incentives in the form of more advantageous tax laws; (4) joint Federal, state and local planning for regional resource development (e.g., oil shale, natural gas, coal); (5) coordinating effort by Federal Government to assist state and local governments in a standardization of Federal, state and local regulation of the industry; and (6) a continuation of supporting R&D, particularly concerning area hydrology, environmental effects, mining technology capable of recovering the thicker deeper deposits and nuclear explosion technology development to provide one more option which could be developed quite rapdily if proven and accepted.

Alternate Methods of Government Participation

Various pieces of legislation have been introduced in Congress recently involving energy R&D, synthetic fuel demonstration plants and development of synthetic fuels industries. A comprehensive bill, The National Energy Research and Development Policy Act of 1973 (S. 1283), introduced by Senator Henry Jackson with 27 sponsors on March 19, 1973, would establish an energy research management project to research, develop, and demonstrate fuels and energy technology and information, and to provide for the coordination and financial supplementation of Federal energy research and development. The bill would authorize corporations to demonstrate technologies for the development of shale oil, coal gasification, advanced power cycle, geothermal steam, and coal liquefaction, and would direct the Secretary of the Interior to make mineral resources of public lands available for the use of these corporations. The following forms of Federal assistance and participation are described in Section 107.

(1) Joint Federal-industry corporations;

(2) Contractual arrangements with non-Federal participants including corporations, consortia, universities, governmental entities, and nonprofit institutions;

(3) Contracts for the construction and operation of federally owned facilities;

(4) Federal purchases or guaranteed price of the products of demonstration plants or activities; and

(5) Federal loans to non-Federal entities conducting demonstration of new technologies.

Congressman Mike McCormack, Chairman of the Subcommittee on Energy of the House Committee on Science and Astronautics and nine cosponsors introduced the proposed Shale Oil Development Corporation Act, H.R. 9693, on July 30, 1973. This bill authorizes the creation of a Shale Oil Development Corporation to bring into being the technology for commercial development of shale oil under a government-industry program, jointly managed and funded, to demonstrate commercial methods of producing environmentally acceptable fuels from the oil shale resources. The Corporation would be authorized to select, on the basis of the best engineering information available, two or more technologically sound, environmentally acceptable, and economically feasible methods for producing a synthetic crude from oil shale. It would construct, maintain, and operate a demonstration-type facility for each method to determine its technical, environmental, and economic feasibility. Finally, it would evaluate the data obtained from these demonstration models; then, for each method deemed economically feasible and environmentally acceptable, it would construct, operate, and maintain a full-scale commercial processing plant.

S. 199 introduced by Mr. Hansen and five cosponsors would allow a tax deduction under the Internal Revenue Code with respect to the amortization of any conversion facility built for the purpose of converting coal and oil to low pollutant synthetic fuels.

H.R. 12014 which was introduced by Mrs. Mink and seven cosponsors would amend the Mineral Lands Leasing Act to establish a public corporation, the Oil Shale Mining and Energy Corporation, to explore and develop all oil shale energy sources on Federal lands. The bill states that non-nuclear in situ or underground retorting shall be the preferred technology to be utilized by the Corporation and prohibits the Corporation from using surface mining techniques.

There would be a high degree of assurance that oil shale demonstration plants would be built and operated under most of these alternatives with the possible exception of the modification of tax laws. A joint Federal-industry corporation would make the government a partial owner and operator of at least the initial plants and would not be consistent with the concept of maximum industry participation and funding. The contracting for construction and operation of Federally owned facilities would reduce industry's role even further. As indicated earlier, direct or guaranteed loans or a guaranteed product price would allow the Federal Government to share the initial risks while keeping industry in the role as owner and operator.

V. Description of Phase II

This study has concluded that the construction of one or more oil shale demonstration plants has the potential of materially accelerating the rate of development of a viable industry if certain other supporting actions are taken by the government, and is worthy of more detailed investigation. The next step would be to form an interagency working group to explore in more detail the implications of such a program, required legislation, and industry's expected response. At the same time an RFP should be prepared for an in depth study of the procedures to be used in working with industry on the demonstration plants, to arrive at more precise cost and schedule estimates and to begin preparation of a detailed RFP which would be used to solicit industry participation in the demonstration projects. This would also involve a study of government and industry needs and desires. Concurrently, an Office of Synthetic Fuels should be established at a high level within FEO/FEA, AEC/ERDA or Interior.

References

1. Final Environmental Statement for the Proposed Prototype Oil Shale Leasing Program, September 1973

2. A. E. Lewis, Nuclear In Situ Recovery of Oil From Oil Shale, Lawrence Livermore Laboratory, UCRL-51453

3. Mineral Facts and Problems, 1970 Ed., U.S. Bureau of Mines, Bulletin 650 (1970)

4. National Petroleum Council Report, "U.S. Energy Outlook Oil Shale Availability", 1973

5. Department of Interior News Release, "Secretary Morton Announces Prototype Oil Shale Lease Sales" dated November 28, 1973

APPENDIX A

Status of Oil Shale Technology

As indicated in the introduction, two general approaches have been considered for the recovery of shale oil each with two major variations. One of these involves mining the shale and retorting it on the surface. The variations being underground and surface mining. The other approach involves rubblizing or fracturing the shale underground followed by in situ processing in which the oil shale is heated in the ground to retorting temperatures and the liberated oil is brought to the surface. The oil shale rubble may be prepared by mining and the use of conventional explosives or by a nuclear explosion with no mining required. Other technologies for creating the increased permeability required for in situ processing are being investigated.

I. Surface Retorting - Room-and-Pillar Mining

All mining of oil shale, since the Bureau of Mines demonstrated a modified room-and-pillar mining system at the Anvil Points Oil Shale mine during the 1948-1956 period, has used this basic mining concept. The Bureau system was developed for mining the near-horizontal oil shale beds of the Mahogany Ledge. These beds of high-grade oil shale vary from less than 15 to more than 150 feet thick with deposits of oil shale that may average 30 gallons of oil per ton. At Anvil Points the Mahogany Ledge contained 73 feet of 28 gallon shale, and was mined in thicknesses ranging from 27 feet to 56 feet to demonstrate the mining method. Since the initial

Bureau demonstration the basic system has been used in three private mining operations for the purpose of furnishing up to about 1,000 tons of shale per day for retorting experiments.

It is believed that the basic technology and equipment prototypes exist that will permit either industry or government to design and excavate an oil shale mine in the richer sections of the Mahogany Ledge that will be able to produce at least 50,000 tons of shale per 24 hours.

If the shale oil bed to be mined is 75 feet thick and contains 25 gallons of oil per ton, 175,000 tons need to be mined each 24 hours to produce 100,000 barrels of oil per day at 97% recovery. If we assume an Anvil Points type mine with 60 foot openings and 60 foot square pillars, the mining operation will extract the ore from an area of 36,000 square feet (75 feet high) or 0.83 acre each 24 hours. When pillar space is added we find the area covered is about 62,000 square feet or 1.42 acres. Thus, including pillar space, the mining operation would require about 36 acres per month or 432 acres per year. This is a mining production rate that has never been accomplished before, either in tonnage per day from an underground mine or in square feet of space required to be mined per day to meet this per day production. Current production from underground mining operations seldom exceeds 60,000 tons per day and this is from block-caving operations where ore deposits are much thicker than the one of 75 feet discussed here.

Beneath the Mahogany lies a "leached zone" and a "deep zone" both of which contain oil shales of sufficient grade and thickness so that the oil shales of these zones represent the major oil shale resource in Colorado. Little is known of the problems of mining these oil shales. Exploration by drilling has established the location and grade of these shales and has also shown that the deeper shales contain quantities of dawsonite and nacholite that may have commercial value. This exploration has also indicated that the "leached zone" contains large quantities of saline water. Any mining in or below this leached zone would have to contend with this water. One company proposes to sink an inclined shaft on the dip of the shale and mine below the water table. This may be possible at the proposed location but is not considered possible in the major portion of the deep basin. A discussion of surface retorting follows the next section.

II. <u>Surface Retorting - Open Pit Mining</u>

Surface mining of oil shale has been considered by some and Colorado site C-a is generally described as a potential test location for this mining system. As the price of oil is increased during this energy shortage, it becomes more apparent that a mining method for the Colorado shales is needed that will provide the optimum utilization of the resource. Open pit mining of the entire deep portion of the basin may be such a system. This may become increasingly evident as the price and need for oil continues to rise.

Open pit mining of the required scale has never been done. However, one U.S. open pit mine has mined about 1,000,000 tons of ore and waste per day using current technology and equipment. With indications that the deep basin of Colorado may contain over 700 billion barrels of 20 gallon per ton oil shale, it should be a government responsibility to investigate all possible methods to add this potential energy to the United States energy resource.

Surface Retorting Processes

Various surface retorting process are described below. They will be similar for both mining methods but may differ somewhat because of the grade of oil shale supplied. Room and pillar mining will probably be used to supply oil shale containing more than 30 gallons per ton of shale oil. Open pit mining will supply oil shale down to 20 gallons per ton. The 20 gallons per ton shale will be easier to handle because it will be less "sticky" but it contains less organic material and may require somewhat different retorting conditions.

A. TOSCO II Process

The central feature of the TOSCO II process is a rotary kiln in which retorting is accomplished by mixing externally heated balls with preheated shale crushed to minus 1/2 inch. The balls are separated from the hot, spent shale and recirculated through a ball heater. Products are drawn off to a collection system for removal

of dust and recovery of liquids and gases. The process utilizes all the shale that is mined, has good heat transfer in the solid-to-solid system, and gives high yields.

A pilot plant designed for about 1,000 tons per day was operated at various times over a period of several years ending early in 1972. This plant was located on Parachute Creek on privately owned land which could also be used as the site of a commercial-scale plant. The pilot plant operations were conducted by the Colony Development group which has as participants Atlantic Richfield Oil Company, The Oil Shale Corporation, Standard Oil Company of Ohio, and Cleveland Cliffs Iron Company. However, in the latter stages of the testing program and in the engineering design of a commercial plant which has resulted from it, only Atlantic Richfield and The Oil Shale Corporation appear to be active participants. Engineering design of the commercial plant will presumably be completed so that construction could start in the fall of 1974.

B. Union Oil Company of California Process

This process employs a countercurrent flow of oil shale and air in a vertical refractory-lined vessel. It operates on a downdraft principle and the shale is moved upward through the retort by a charging mechanism referred to as a rock pump. Heat is supplied by combustion of the carbonaceous residue remaining on the retorted shale and shale feed rates are adjusted to maintain the combustion

zone a short distance below the surface of the bed. Some of the product oil is condensed by the cool incoming shale and is recovered as a liquid while the remainder exits with the gas. The retort uses lump shale of about 3-inch maximum size, must have fine material removed, and does not require cooling water.

The process was tested in 1957 and 1958 in a pilot plant having a design capacity of 1,000 tons per day. The plant was located on Parachute Creek on private land which was presumably to be suitable for commercial exploitation. Following completion of the pilot plant program it was announced that tests had been successful and the process could be commercialized in the proper economic climate. It isn't known how much planning for a demonstration-scale plant has been done by the company since 1958, but presumably some consideration has been given to such a plant. Hence, it seems reasonable that design of a demonstration plant could be completed in about one year. Union Oil recently announced that a 50,000 barrel per day plant is being planned for construction on private land and could be in operation by 1979.

C. Gas Combustion Process

The gas combustion retort employs a vertical refractory-lined vessel through which crushed shale moves downward by gravity countercurrent to the retorting gases. Recycled gases enter the bottom of the retort and are heated by the hot, retorted shale as they pass upward through the vessel. Air and some additional recycle gas are injected into the retort through a distributor system at a point

approximately one-third of the way up from the bottom and are mixed with the rising hot recycled gases. Combustion of the gases and of some residual carbonaceous material heats the shale above the combustion zone to retorting temperature. Three systems utilizing this basic concept have been developed by different groups.

(1) Bureau of Mines and Colorado School of Mines Research Foundation--

The Bureau of Mines first developed and tested the gas combustion process during the 1950's in three pilot plants having capacities of 6, 25, and 150 tons per day. Investigations were terminated in 1956 after only a small amount of work had been done on the largest of these retorts and before operability of the process on this scale had been established.

Further developmental efforts on the gas combustion retort were conducted between 1965 and 1968. During this period the Bureau of Mines facilities were leased to the Colorado School of Mines Research Foundation and were operated by it under a research contract with six oil companies: Mobil, which acted as project manager; Humble; Phillips; Sinclair; Pan American; and Continental. This research utilized the same three retorts that the Bureau had built earlier and was concerned with such variables as shale flow in the retort and design of systems for injecting air into the retort. Results showed that the process could be operated at throughput rates of about 500 pounds per hour per square foot of bed area (about twice the rates

achieved by the Bureau of Mines) without seriously decreasing the yield. However, all problems in operating the equipment were not solved, particularly insofar as the largest of the three units was concerned. Hence, the next step in development of this process would be construction and operation of a scaled-up unit handling perhaps 1,000-5,000 tons per day.

(2) Cameron Engineers and Petrobras--Cameron Engineers and Petrobras, the Brazilian governmental petroleum corporation, have cooperated in developing the Petrosix process which is a modification of the gas combustion system in which the recycled gas is burned outside the retort and the hot gases used for retorting. Because no combustion takes place in the retort, the system should eliminate, by more precise temperature control, clinker and agglomerate problems. This process is being tested in Brazil in a plant designed to process 2,500 tons of shale daily with yields of approximately 1,000 barrels of oil, 1,000,000 cubic feet of gas, and 20 tons of sulfur per day.

(3) Development Engineering Incorporated--Development Engineering Incorporated has developed some modifications to both the internal and external combustion modes of operating this process. The internal combustion option has been utilized successfully for the calcining of limestone and, if it can be applied successfully to oil shale, it should substantially lower the capital investments involved in a plant. A 30-month program, known as the Paraho program, has just

started under the sponsorship of the following 17 participating industrial companies to test both the internal and external options of this process.

PARAHO DEVELOPMENT CORPORATION

1. SOHIO Petroleum Company
2. Gulf Oil Corporation
3. The Cleveland-Cliffs Iron Company
4. Southern California Edison Company
5. Arthur G. McKee and Company
6. Kerr-McGee Corporation
7. Shell Development Company
8. Standard Oil Company (Indiana)
9. The Carter Oil Company
10. Mobil Research and Development Corp.
11. Webb Resources Inc. Group
12. Sun Oil Company
13. Texaco, Inc.
14. Phillips Petroleum Company
15. Atlantic Richfield Company
16. Marathon Oil Company
17. Standard Oil Company of California

It will require about 3 years for this process to reach the stage where TOSCO II now is under a normal development schedule.

D. Superior Oil Company Process

Superior proposes a process differing from the others in that it is primarily a concept for mining and production of multiple products rather than hardware for a specific retorting process. It is peculiarly applicable to land owned by Superior on the north side of the Piceance Basin if Superior's present holdings can be suitably blocked up by an exchange with the Federal Government. The concept is to start on an outcrop of the lower zone shale which contains oil shale, nacholite, and dawsonite and to run a drift to a mineable portion of this bed staying always below the leached zone so that there will be no water problems.

III. In Situ Retorting Processes - Rubblization by mining

This option calls for mining a cavity of sufficient volume so that after blasting or caving, a rubble column will be formed having a desired bulking porosity, e.g., 20% void volume. Subsequently the oil shale would be ignited and kept burning by means of compressed air and the oil and gases would be removed through drill holes or mined openings.

It must be noted that this process requires underground mining. Substantial amounts of shale must be removed to the surface (20 to 30% of the amount required by room and pillar mining for surface retorting, assuming equal oil production from 20 gallons per ton oil shale. This oil shale removed represents material that will require disposal on the surface either as is (if very lean shale) or after surface retorting (if moderate to rich in oil content).

The technology for this process is less developed than that of surface retorting. Only one publicly announced test of this process has been done by Occidental Petroleum Company. Yield was purported to "approach" 70% of oil assay (25 gal/ton). The scale of the field test was small (75 ft. high column, 35 ft. on a side) compared to the scale envisioned for commercial production (hundreds to 2000+ feet high, and at least hundreds of feet on a side). The success of scaling up to these larger thicknesses and greater column cross-sections appears likely, but of course must be considered to be uncertain.

Some R&D has been done on other methods of fracturing and retorting oil shale in place. One technique which has been proposed for shale preparation prior to in situ retorting calls for the use of solvents. The process developed by Shell Oil Company involves injecting water or other solvents into a shale formation in order to dissolve some of the associated minerals. The removal of these minerals, which are later recovered, creates the permeability required to support in situ combustion. The Bureau of Mines has also conducted experiments involving hydraulic fracturing and chemical explosives to provide sufficient permeability and surface area for in situ processing. Fractures are initiated from a multiwell development pattern. After fracturing, the oil shale is ignited at a centrally located well. The combustion zone passes horizontally through the shale and the products are removed from the peripheral wells. Another in situ process

which has been tested by Equity Oil Company involves the use of naturally occurring fractures. Hot fluids, either natural gas or steam, are injected into these fractures to accomplish retorting and the products are subsequently collected. Except for the Bureau of Mines experiments, no details of the above processes have been published. The technologies appear promising, but are not believed to be within the realm of near term commercial development.

IV. In Situ Retorting - Rubblization by nuclear explosives

In this option rubble is produced by detonating a nuclear explosive near the bottom of thick oil shale beds. Air, exhaust gases and oil are transported through drill holes. No mining is required. Other parts of the process are identical or similar to the in-situ retorting of rubble produced by mining. The oil would contain slight amounts of tritium. (A population in an area using only oil from this source would receive radiation equivalent to no more than 0.1% of natural background). This option has the potential of producing the least expensive oil with the minimum effect on the environment. The use of nuclear explosives, however, does not appear to be publicly acceptable at this time. This technology will therefore develop slowly if at all and the population influx into the sparsely populated Piceance Creek Basin brought about by other development may preclude its use in the future because of ground motion caused by repeated nuclear detonations.

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APPENDIX B

Advantages and Disadvantages of Four Oil Shale Development Approaches

I. General Comparisons

In this section the advantages and disadvantages of the various approaches for developing the oil shale are discussed. The four basic methods are the following:

I. Surface retorting of oil shale obtained by mining underground;

II. Surface retorting using open pit mining;

III. In situ retorting in chimneys after mining out a fraction (10-25%) to provide bulking space for the oil shale which is blasted into a rubble; and

IV. In situ retorting after using nuclear explosives to create oil shale rubble.

These are described in more detail in Appendix A. In order to make an evaluation they were considered in the light of:

1. Cost per barrel and capital investment required;
2. Potential for improvement of the technology and economics;
3. Resource utilization;
4. Environmental effects;
5. Safety of workers;
6. Special limitations and risks; and
7. Schedule to reach 100,000 barrel per day and 1,000,000 barrel per day operations.

Oil yields of each process are important in assessing the relative importance of each option. Yields of oil based on assay are as follows:

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	Yield, % of Assay	Potential Improvement by R&D, Yield %
Surface retorting	95*	---
Mining in situ		
in situ portion	60	75 - 85
surface portion	95	---
overall average	67	70 - 80
Nuclear in situ	60	70 - 80

*NPC calculations assumed 100% yield and 96% recovery in upgrading operation. We assumed 95% yield and no loss in upgrading. Results agree well within uncertainty of the estimates in this report.

Since there is both a short and long term energy shortage in the USA and the world, the extent of utilization of the oil shale resource is important. Another important item is the net energy yield of each option considered. Each process consumes energy in the production of oil. The energy may be consumed directly, as in power usage for air compressors, ventilation equipment and fuel for trucks and earth moving equipment, etc. The energy consumption may be indirect, for example, in the production and fabrication of steel for piping, surface retorts, drill rigs, etc. Incremental energy may even be consumed in servicing a growing population in the area needed for production operations. It is difficult to calculate all the energy consumed in producing oil from shale. However, both operating and capital costs of producing oil shale are probably closely related to the amount of energy consumed in production.

Thus, those options that produce oil at lowest cost probably also consume the least energy and give the highest net energy per barrel of oil produced.

More detailed calculations on net energy are desirable, but are beyond the scope of this report.

Costs were calculated on the basis of no taxes or land (royalty) costs, annual return on investment of 15%, and 20 year life of capital investment. These are arbitrary assumptions to permit comparisons on a uniform basis. NPC estimates were based on constant 1970 dollars. LLL costs were based on constant 1973 dollars. No attempt was made to reconcile these different year bases. In the course of this report, calculations made at one grade (assay) of oil shale had to be converted to those at another. The assumption was made that for each mining type, mining and surface retorting costs are constant per ton of material handled. It was also assumed that oil yield in percent from each process is independent of the assay. Thus, mining and retorting costs are inversely proportional to the assay. Upgrading costs per barrel of oil are independent of assay. All options except shallow underground (room-and-pillar) mining require dewatering in most of the oil shale. The cost was estimated using reasonable assumptions on transmissivity of the aquifer and amount to about 20¢ to 29¢ per barrel of oil produced.

Comparisons

A. Costs

Costs are comparable for most options except that:

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TABLE 6

OPTION	Years to prod. Population influx: 100,000 Bbl/D	Years to prod. Population influx: 1 Million Bbl/D	Cost $/Bbl	Resource Base (Billion Bbl): In-Place	Resource Base (Billion Bbl): Recov.	Cap. Cost $/Bbl	Environment: Waste Disposal for 1 Million Bbl/D	Environment: Other Concerns	Worker Environment & Safety (annual fatality per 1 Million Bbl/D	Potential for Improvement of method (i.e., reduced environmental affects and lower cost)	Possible problems
I - Room & Pillar Mining Surface Processing	4 15K	8-12 150K	(35gpt) 6.17 LLL, 4.37 NPC (30gpt) 6.95 LLL, 4.95 NPC	34 100 Min. resource utilized	20 54	2.70	.5 billion tons/yr Intermediate disposal problem	Water use & quality Max. popul. influx	39 fatalities/yr Max. number of underground miners	Some improvement possible in retorting	Ultimate production rate may be limited by water requirements
II - Open Pit Mining Surface Processing	3-4 15K	8-12 150K	(20gpt) 6.42 LLL, 6.88 NPC	800 Max. resource utilized	760	3.33	1.5 billion tons/yr Max. disposal problem	Water use & quality Dewatering & hydrol. effects, max. popul. influx	17 fatalities/yr Large surface operation	Some improvement possible in retorting	Ultimate production rate may be limited by water requirements
III - In Situ with Mining	4 9K	7 99K	(20gpt) 4.86*LLL incl. NPC retort & upgrade	800	300	2.23* 1.13 w/o upgrading	.23 billion tons/yr	Dewatering & hydrol. effects, intermediate popul. influx	26 fatalities/yr Large number of underground miners	Major improvement possible in cost & utilization of resource if yield is improved	May be uneconomical if mine safety problem is too expensive to solve.
IV - In Situ Nuclear	2-3 6K	6-7 66K	(20gpt) 3.42*LLL incl. NPC upgrade	650+	200+	1.24*	None No disposal	Ground motion. slight radioactivity in product, Dewatering & hydrol. effects, Min. popul. influx	7 fatalities/yr Drilling operation No underground	Major improvement possible in cost & utilization of resource if yield is improved	May be unusable if radioactive leakage cannot be prevented. Public acceptance

*Note Includes NPC upgrading costs. If this is not required, capital costs are reduced by $1.10/B and total costs are reduced by 1.56.

**Includes 15% return of capital - 20 years does not include taxes and land.

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